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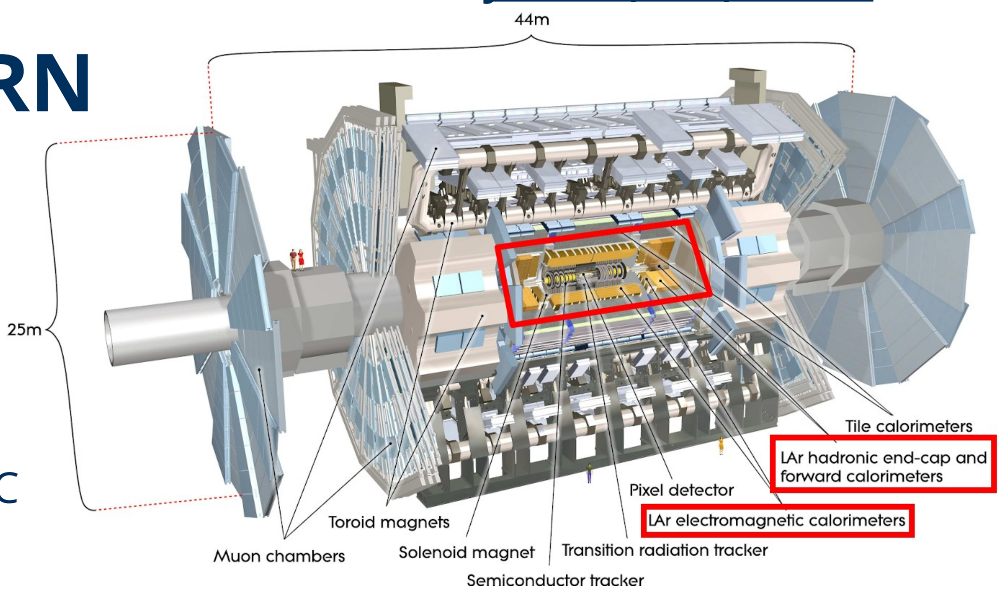
On behalf of the ATLAS Liquid Argon Calorimeter group

Current and future challenges when operating the ATLAS Liquid Argon Calorimeter

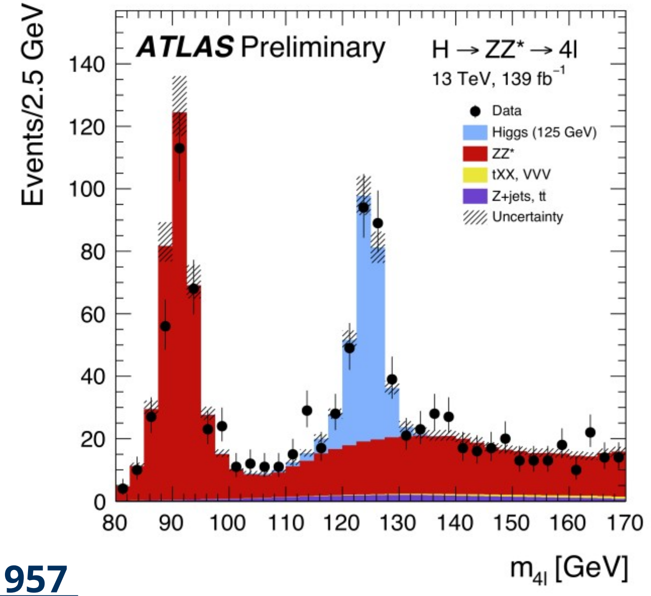
LIDINE 2023: LIght Detection In Noble Elements
Madrid, 20-22 September 2023

[JINST 3 (2008) S08003]

Introduction: ATLAS and LHC at CERN

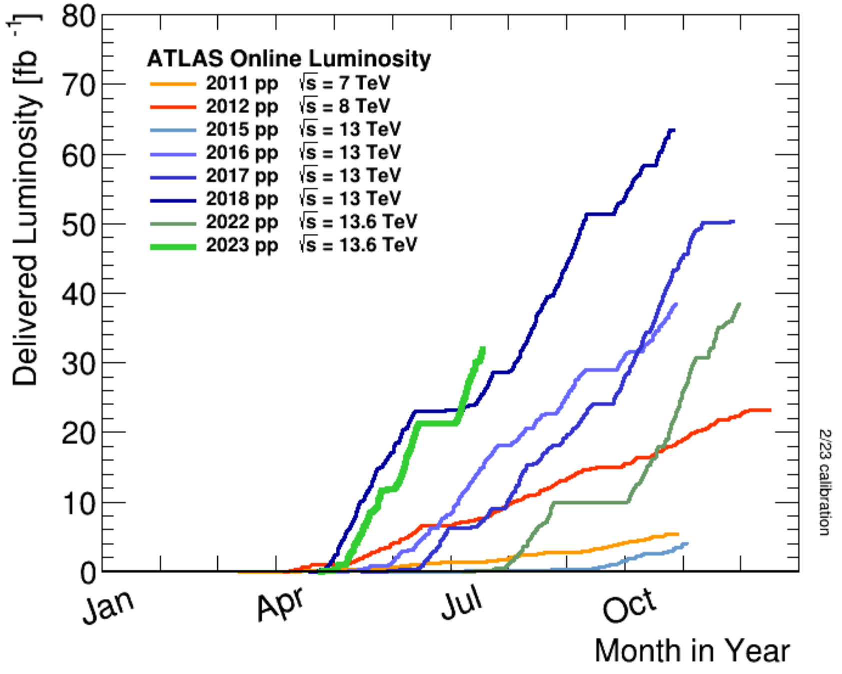


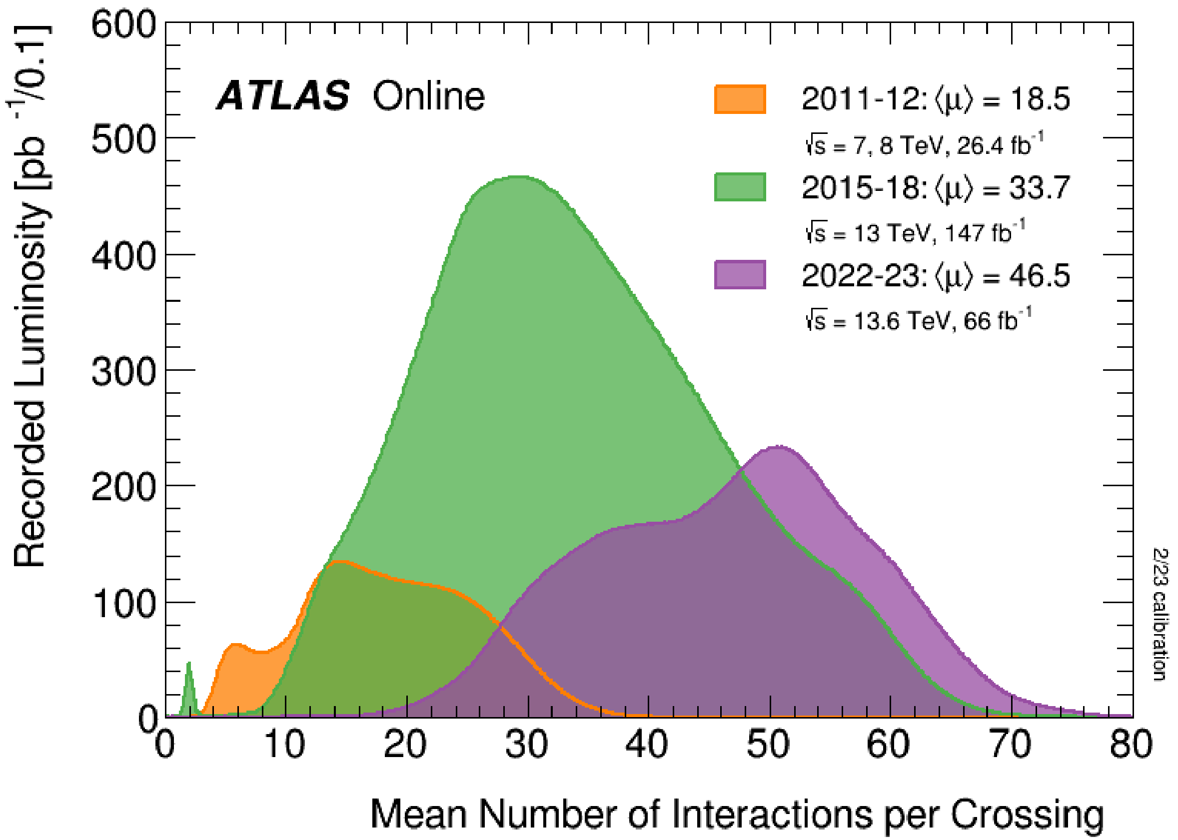
- **Large Hadron Collider** (**LHC**) = largest and highest energy particle accelerator
- Completed at **CERN** in 2008, since 2010 in operation for physics
- **ATLAS** is one of the two large, **general-purpose** experiments at the LHC
- Main physics goals:
  - ⇨ Understand origin of mass: search for a **Higgs boson** ✓
  - ⇨ Precision measurements of Standard Model of particle physics (SM)
  - ⇨ Search for physics beyond the SM (e.g. Supersymmetry)
    - Identify candidates for Dark Matter
    - Explain matter/antimatter asymmetry
    - Determine if fundamental forces are unified



[Eur. Phys. J. C 80 (2020) 957]

The LHC environment

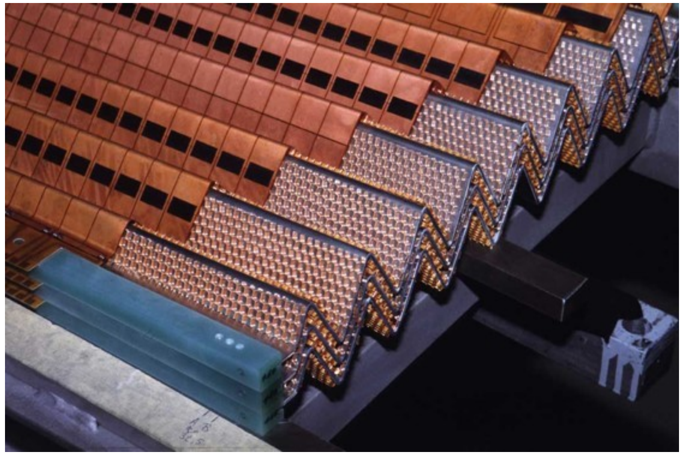


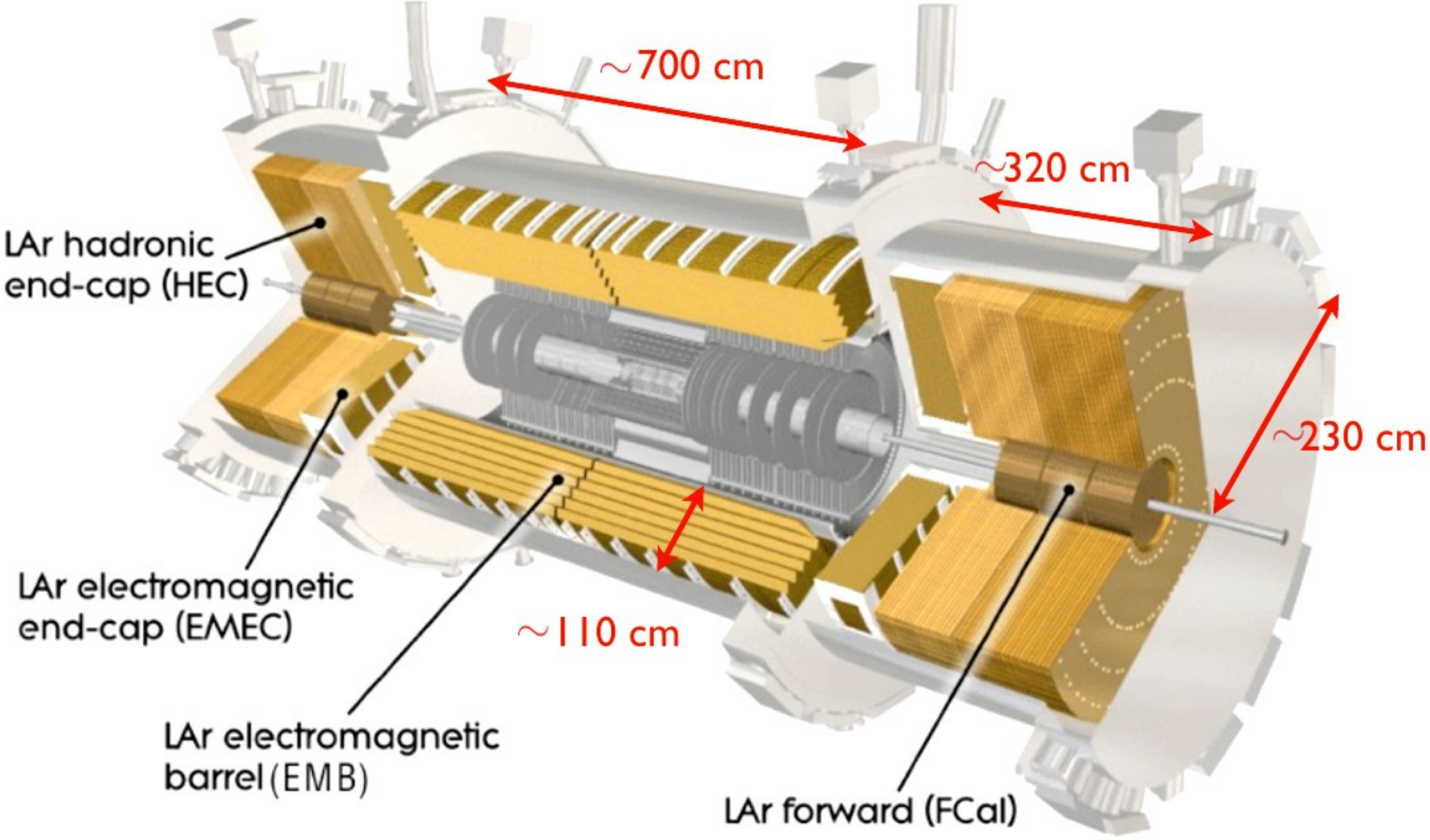


- Proton—proton collisions at **13.6 TeV**
- Nominal LHC bunch crossing frequency: **40 MHz** (25 ns spacing)
- Pileup: multiple interactions per crossing (**~50** for current LHC Run 3)
  - ⇨ Extremely challenging environment for the experiments

The Liquid Argon calorimeter system

- Sampling calorimeter with **Liquid Argon (LAr)** as active medium
- Provides energy measurement and particle identification
- Serves as input for the ATLAS level-1 trigger
- ~ 80 m³ LAr in detector & tanks
- >**182k LAr channels**





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Operation principle and signal readout

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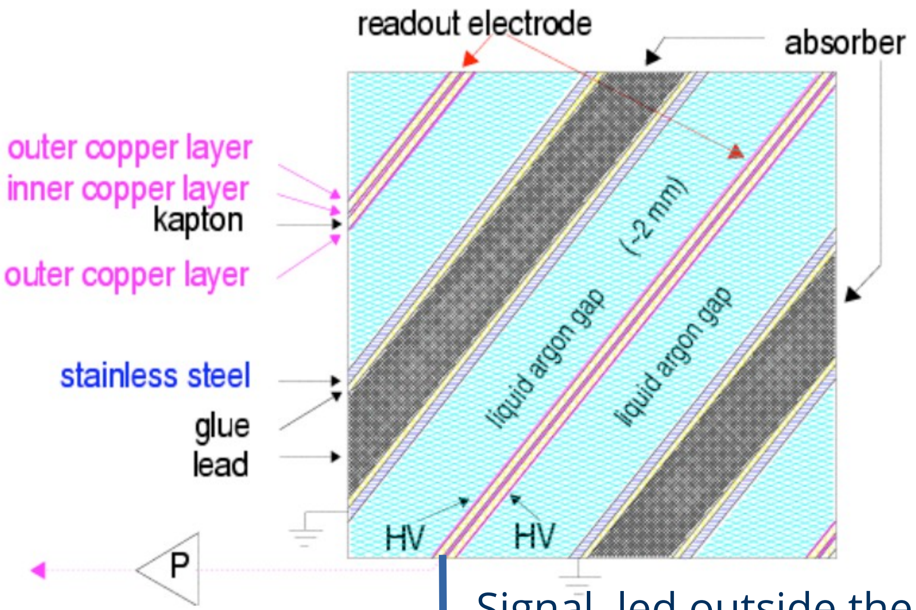
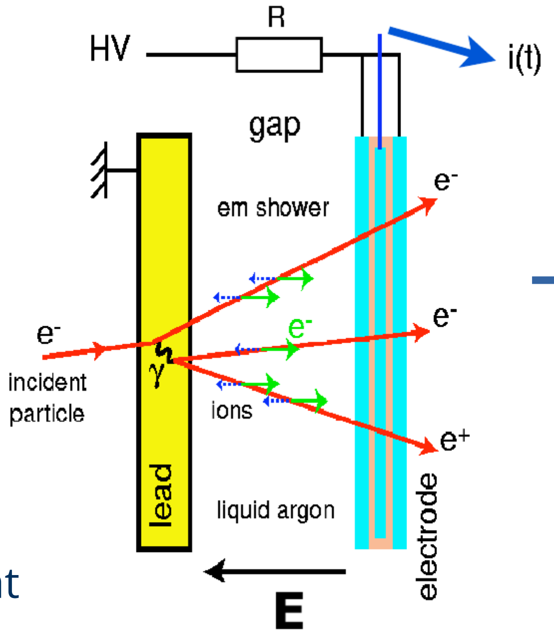
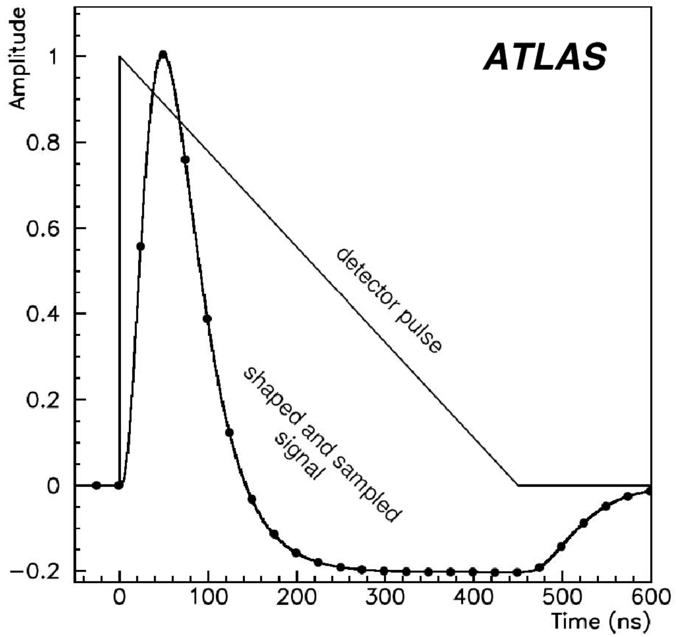


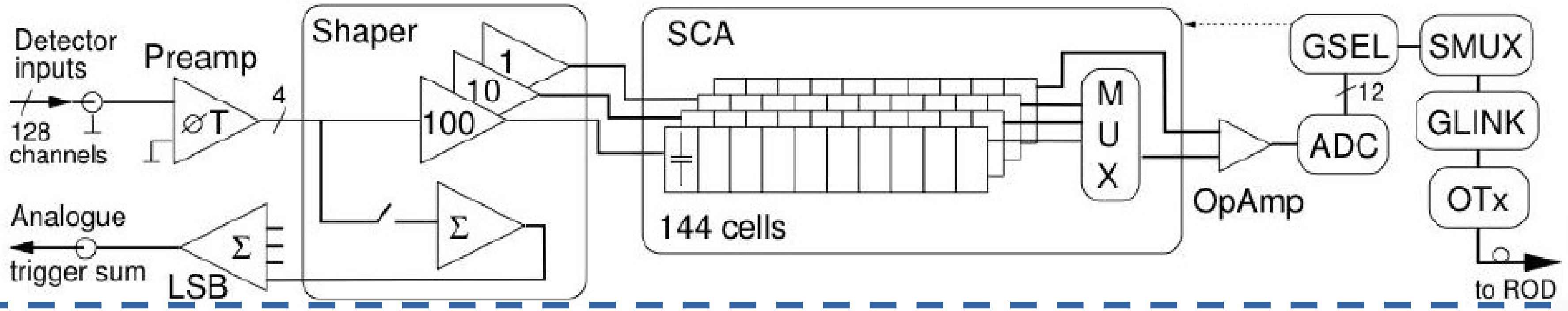




HV of **1-2.5 kV**

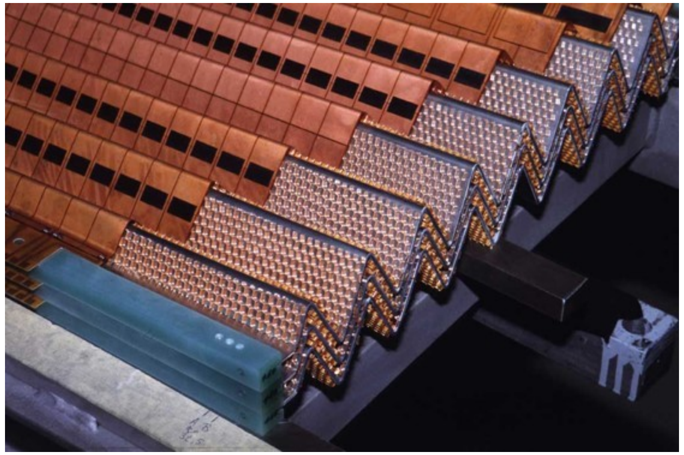
Signal led outside the cryostat via 114 feedthroughs

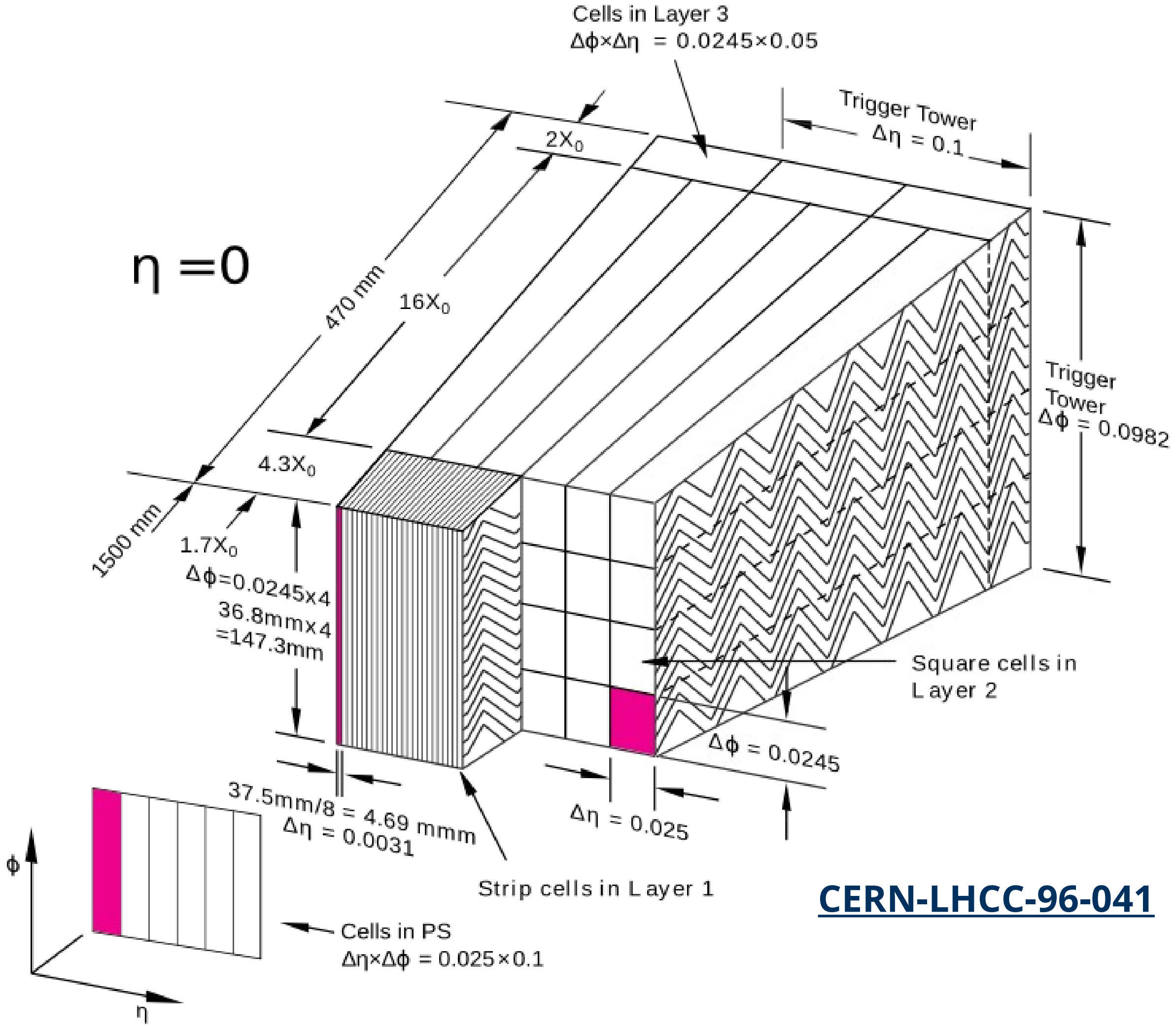
Front End Boards in Front End Crates



EM calorimeter design

- Lead absorber
- 0.9–2.8 mm LAr gaps in barrel
- Accordion geometry: uniform coverage in Φ





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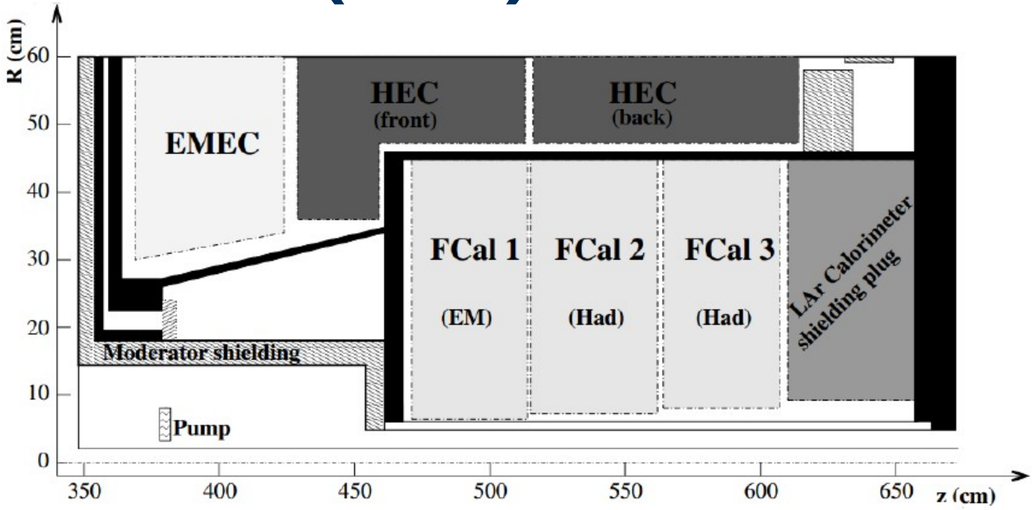
Hadronic (HEC) and forward (FCAL) calorimeter

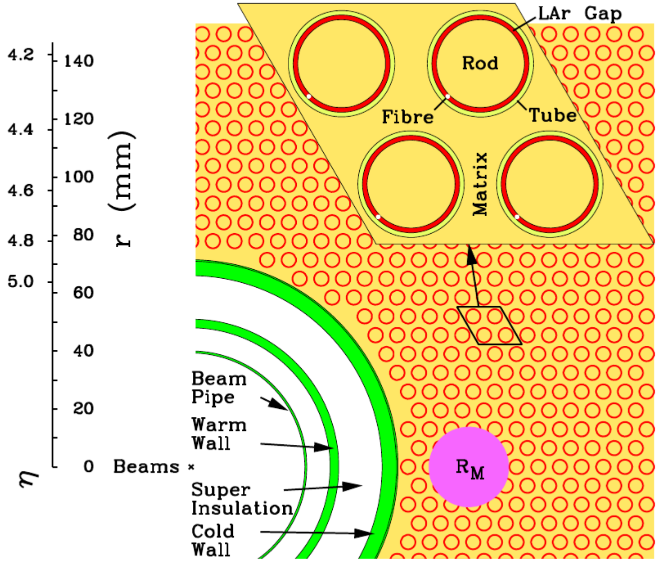


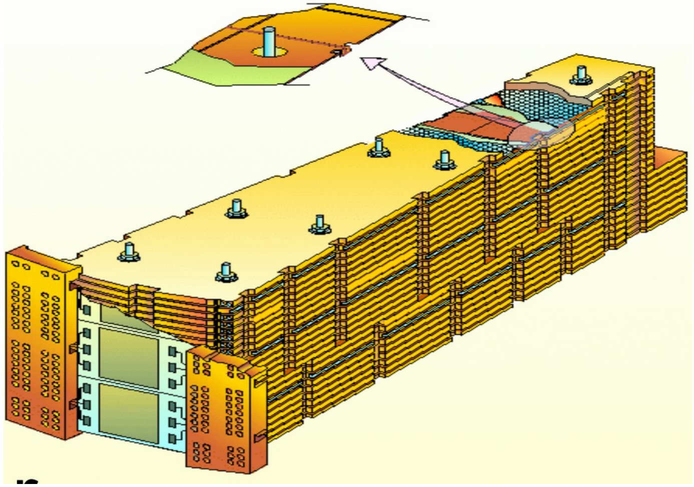
HEC:

- 2 parts Cu-LAr
- Parallel plate electrodes

FCAL:

- 3 parts: one Cu-LAr and two W-LAr
- Novel design with cylindrical electrodes
- LAr gaps: 269/376/508 µm
  - ⇨ Small due to increased particle flux





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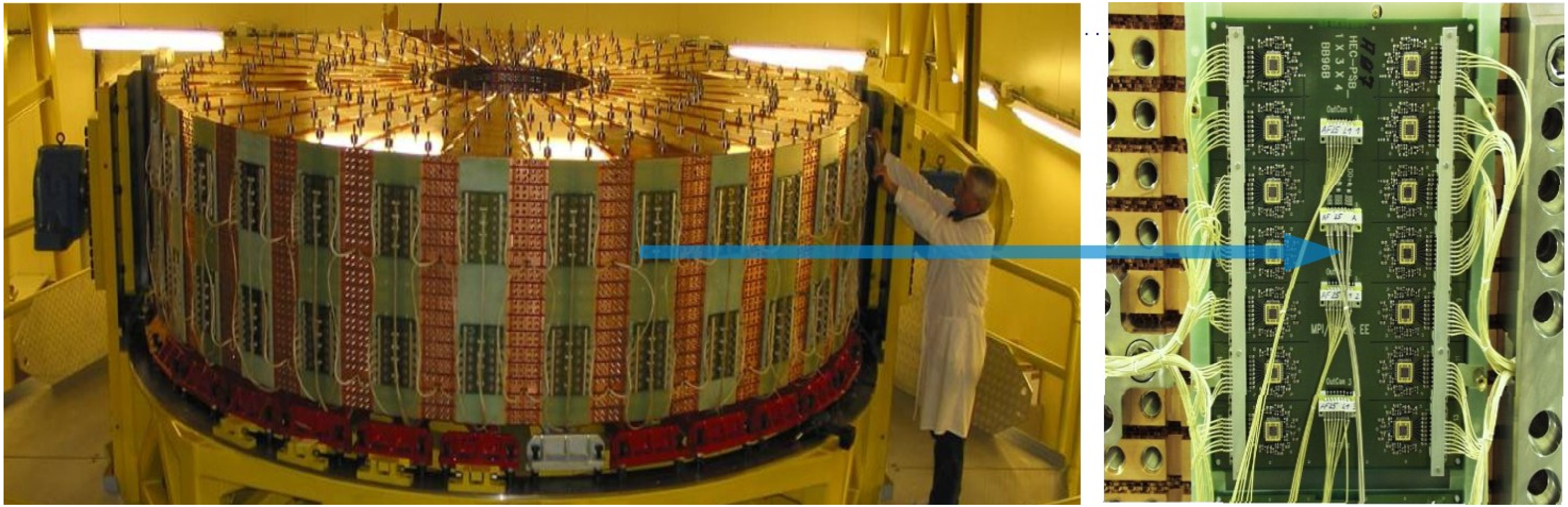
HEC cold electronics



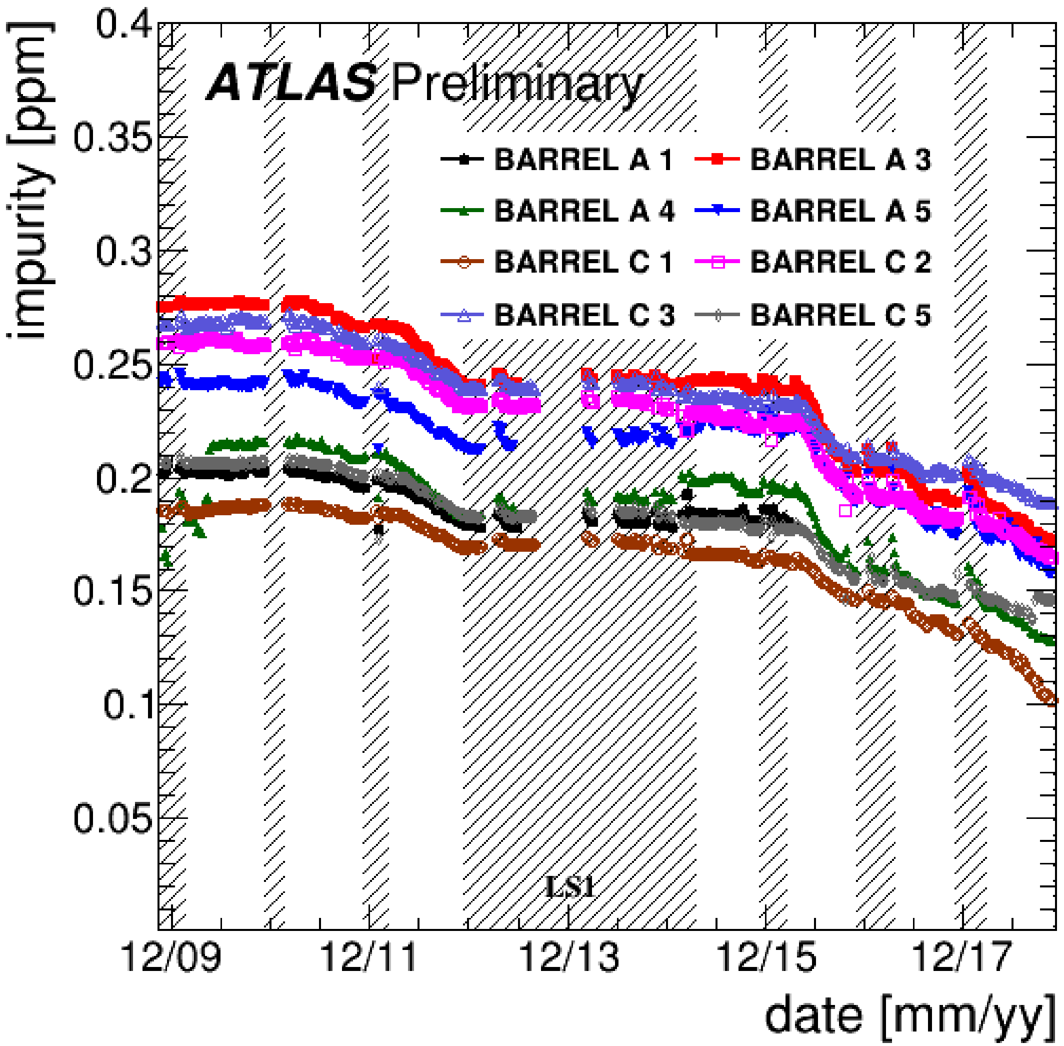
- Only calorimeter with active cold electronics: ~35k preamps, ~9k summing amps, ~5.6k readout channels
- GaAs ASICs at outer radius of the HEC inside cryostat: stable operation at cryogenic temperatures
- After first 6 years only 5 dead channels (< 0.1%)
  - ⇨ No need to replace for HL-LHC

LAr purity

- Electronegative impurities (such as O_2) can degrade the signal measurement
- Monitored with 30 purity monitors in 10-15 min intervals
- Require purity < 1 ppm
- Reached

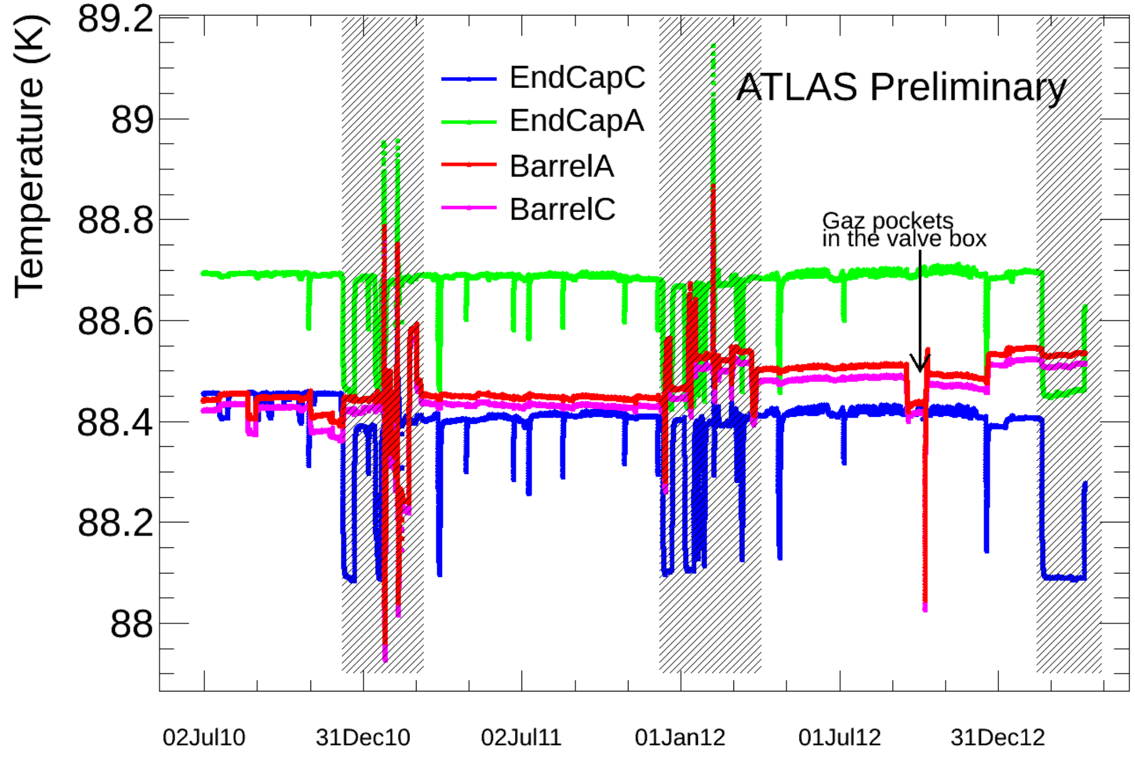
  < 0.28 ppm for the barrel ✓

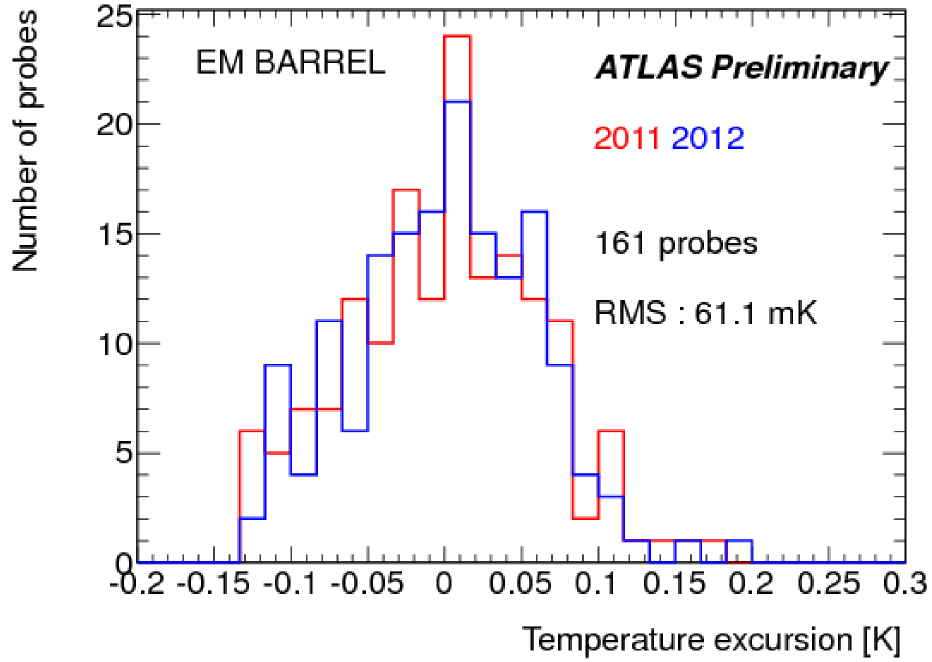
  < 0.18 ppm for the endcaps ✓



LAr impurities in LHC Run 1+2 (2009-18)

LAr temperature

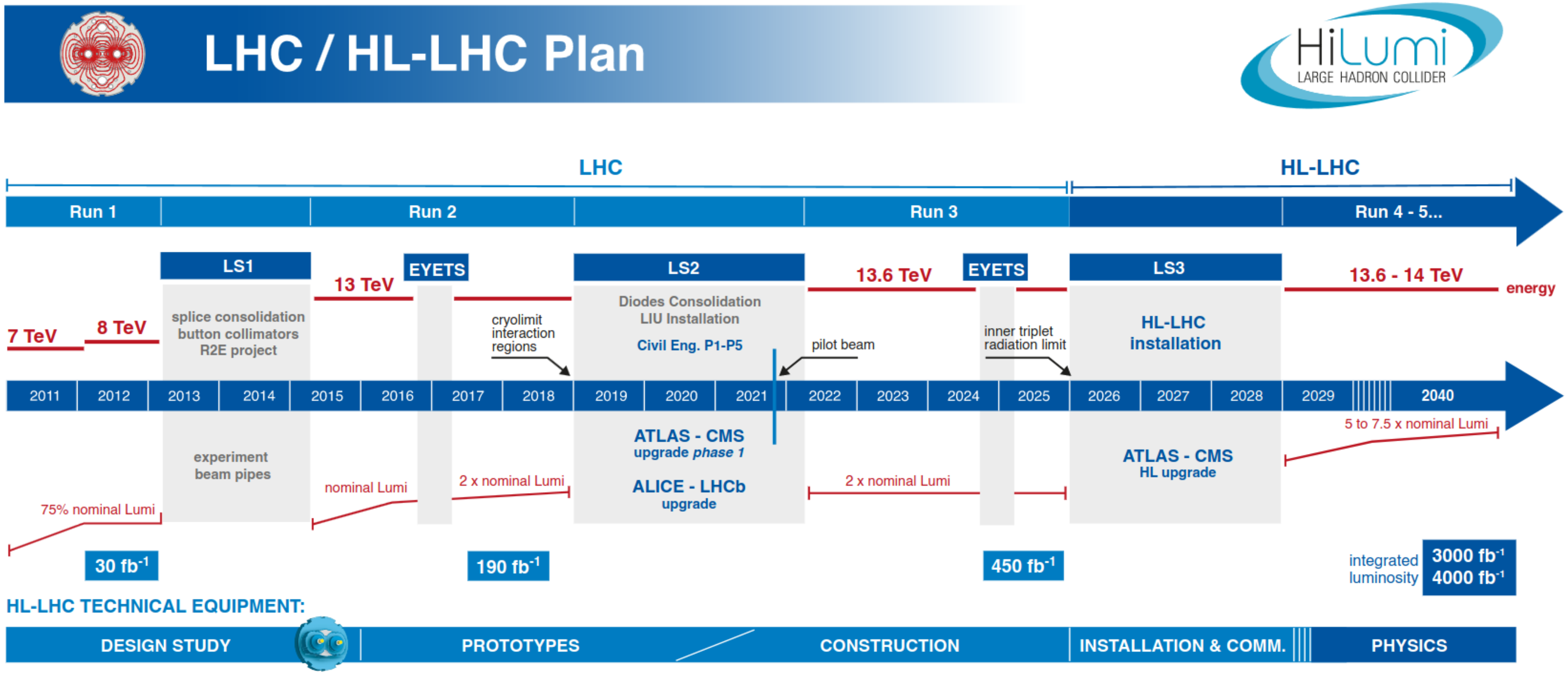




LArCaloPublicResultsDetStatus

- LAr temperature variations impact to energy resolution measured to be: **-2%/K**
  - ⇨ 1.5% from drift velocity and 0.5% from density variation
- 192 sensors in barrel and 158 in each endcap cryostat
- < 100 mK stability and uniformity required
  - ⇨ Measured to 61 mK ✓

LHC schedule and upgrade plans



HighLuminosityLHCProject

- Phase-I upgrade during LS2
  - ⇨ Provided digital trigger inputs to cope with higher luminosities ✓
- Phase-II upgrade during LS3 for HL-LHC starting in 2026

Phase-I upgrade motivation: Super Cells (SC)

- New LAr trigger system for high pile-up environment
  - ⇨ SCs with much **finer granularity** than Trigger
- Better trigger energy resolution
- Higher efficiency in selecting physics objects
- Challenge of much higher data flow (~25 Tbps)

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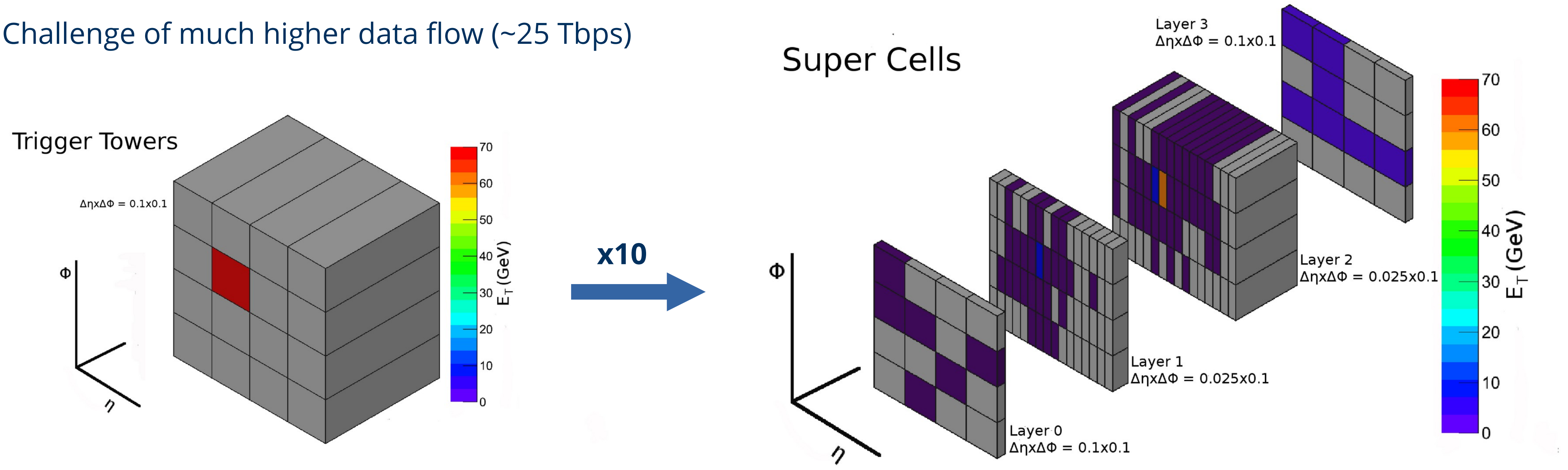
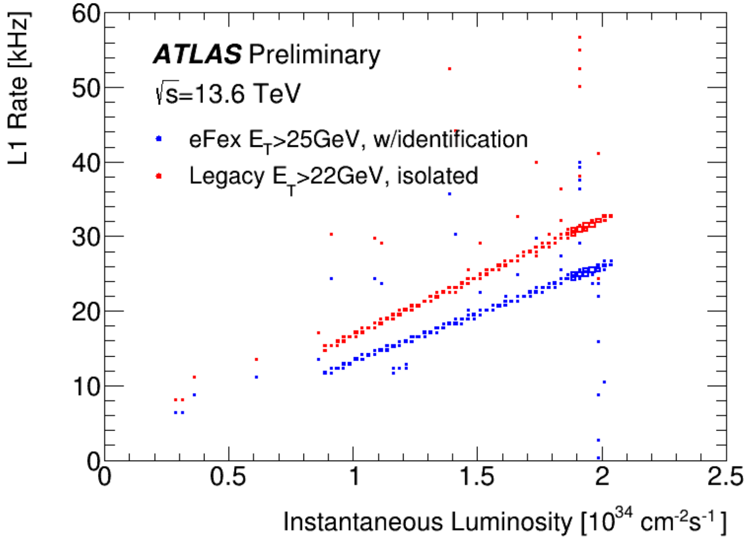
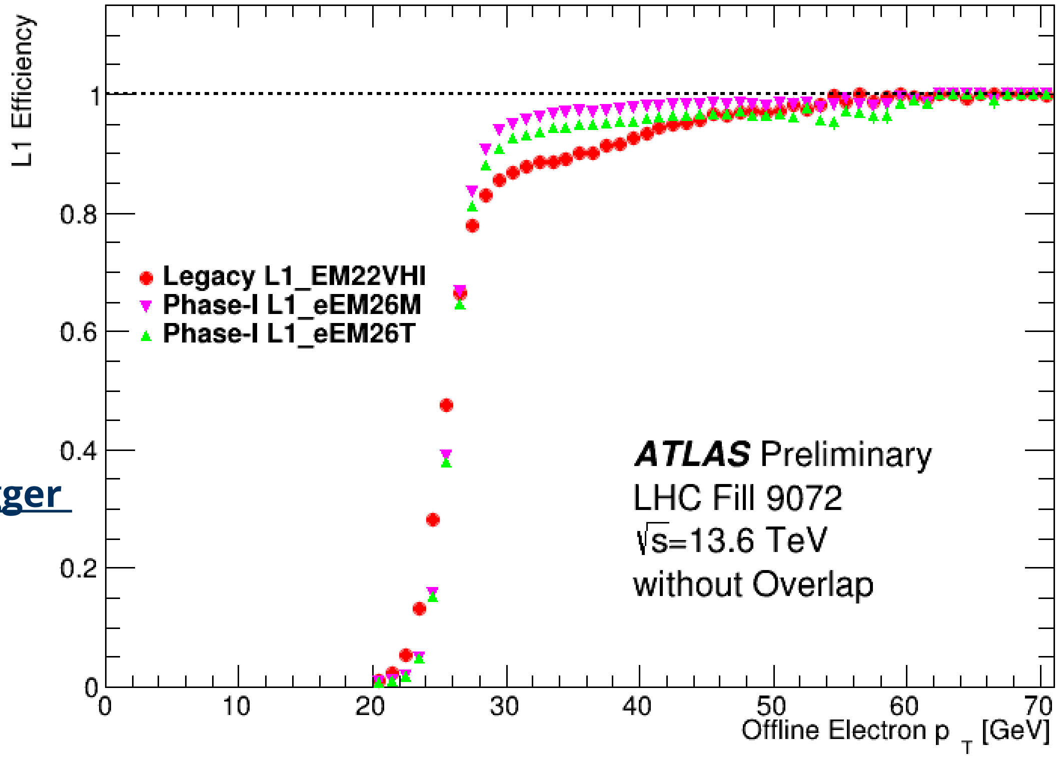
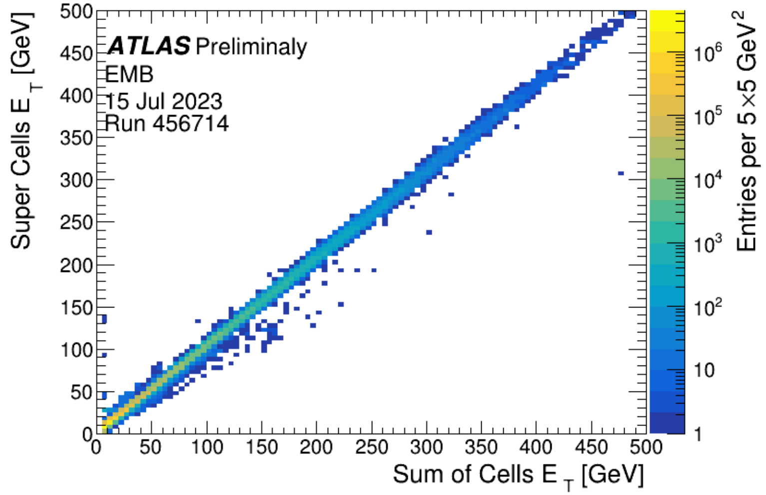


Phase-I trigger performance





[Level-1 Calorimeter Trigger Public Results]



[LArCaloPublicStable Beam2023DT]

- Cell energies correspond well between calorimeter cells and SCs
- Phase-I EM trigger item shows better performance:
  - ⇨ Sharper efficiency turn-on curve
  - ⇨ Lower trigger rate (~80% of legacy EM item)
  - ⇨ Phase-I EM item used as primary trigger now ✓

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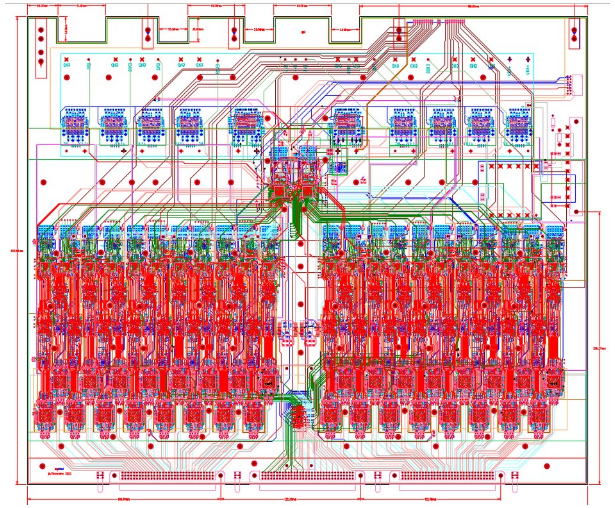
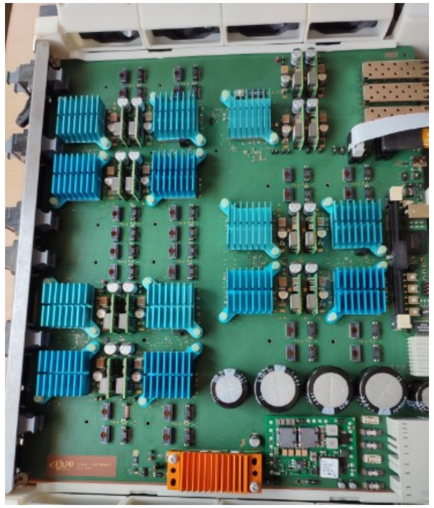
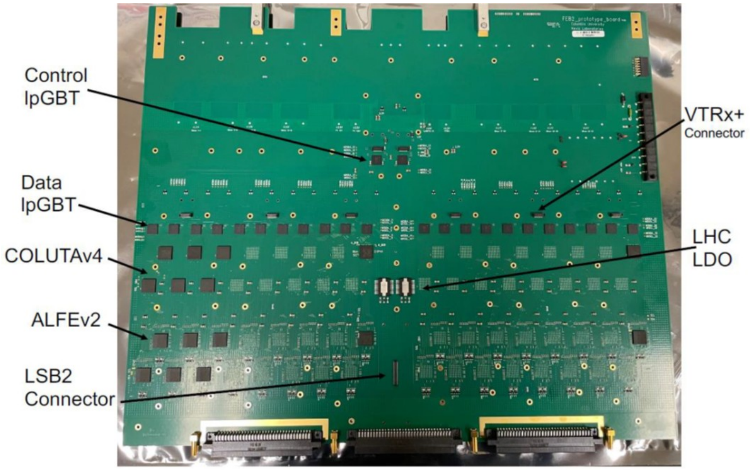
HL-LHC challenges - Phase-II upgrade

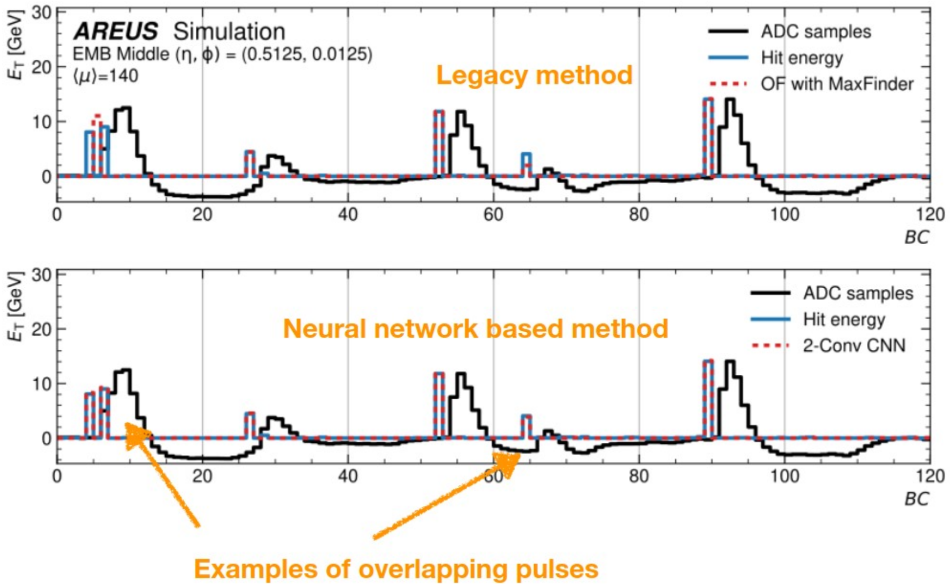




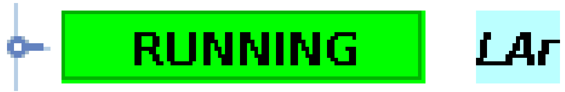
- **HL-LHC**:
  - ⇨ Up to **7x design luminosity**
  - ⇨ Up to **200** simultaneous collisions
- LAr calorimeters themselves expected to **operate reliably**
- **Readout** requires complete **replacement** to cope with increased rates and radiation exposure
  - ⇨ Provide full calorimeter information (**250 Tbps!**) for improved trigger decisions
- New FEBs, calibration boards, processing boards, timing/control/monitoring boards
  - ⇨ Prototype boards of each type in preparation
- Use advanced neural networks for energy computation

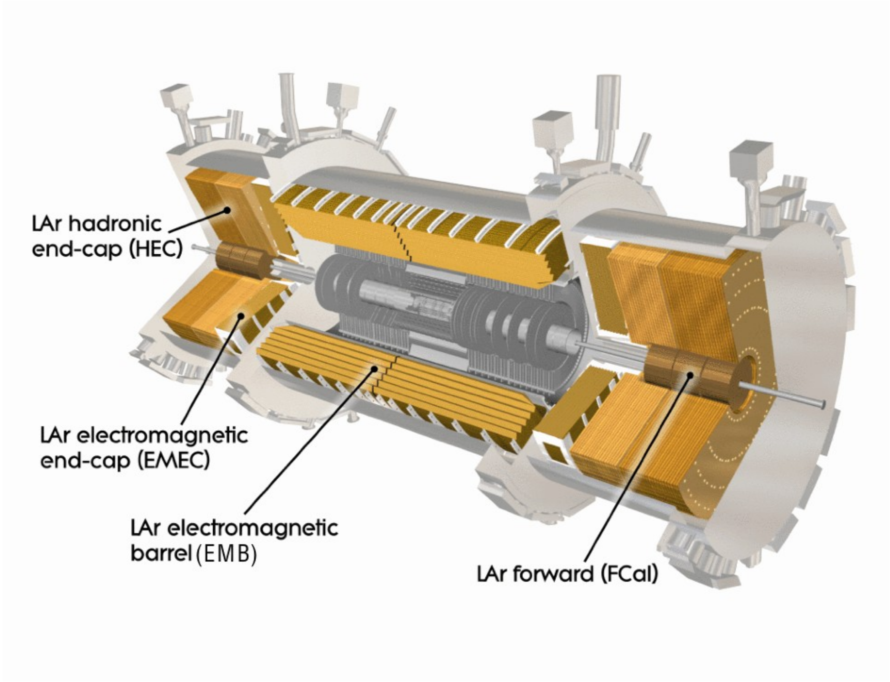


LArCaloPublicResultsUpgrade

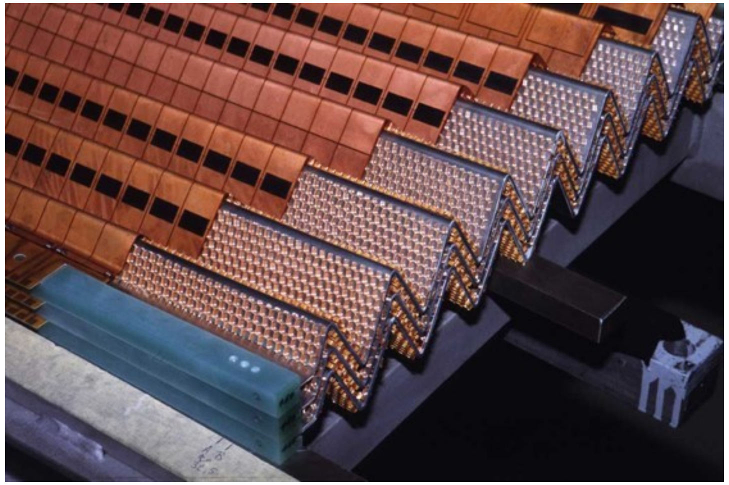


Summary





- LAr calorimeter performing exceptionally well in a challenging environment
- Trigger system successfully upgraded during LS2
- On track for Phase-II readout upgrades



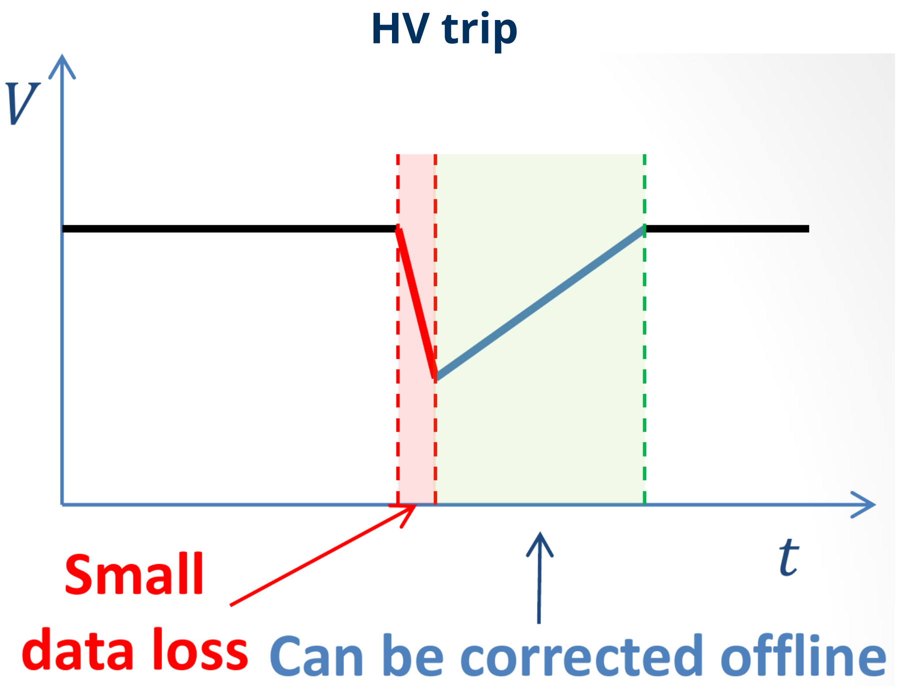
Thank you for your attention!

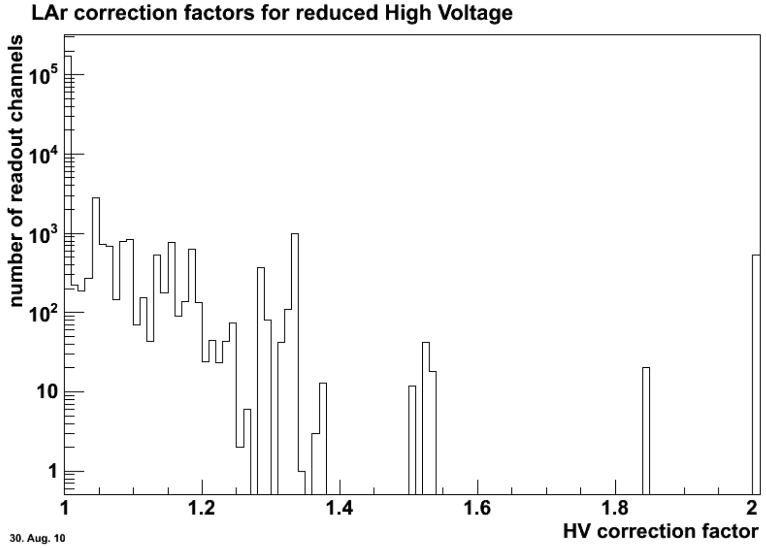
Questions?

Backup

High voltage system operation

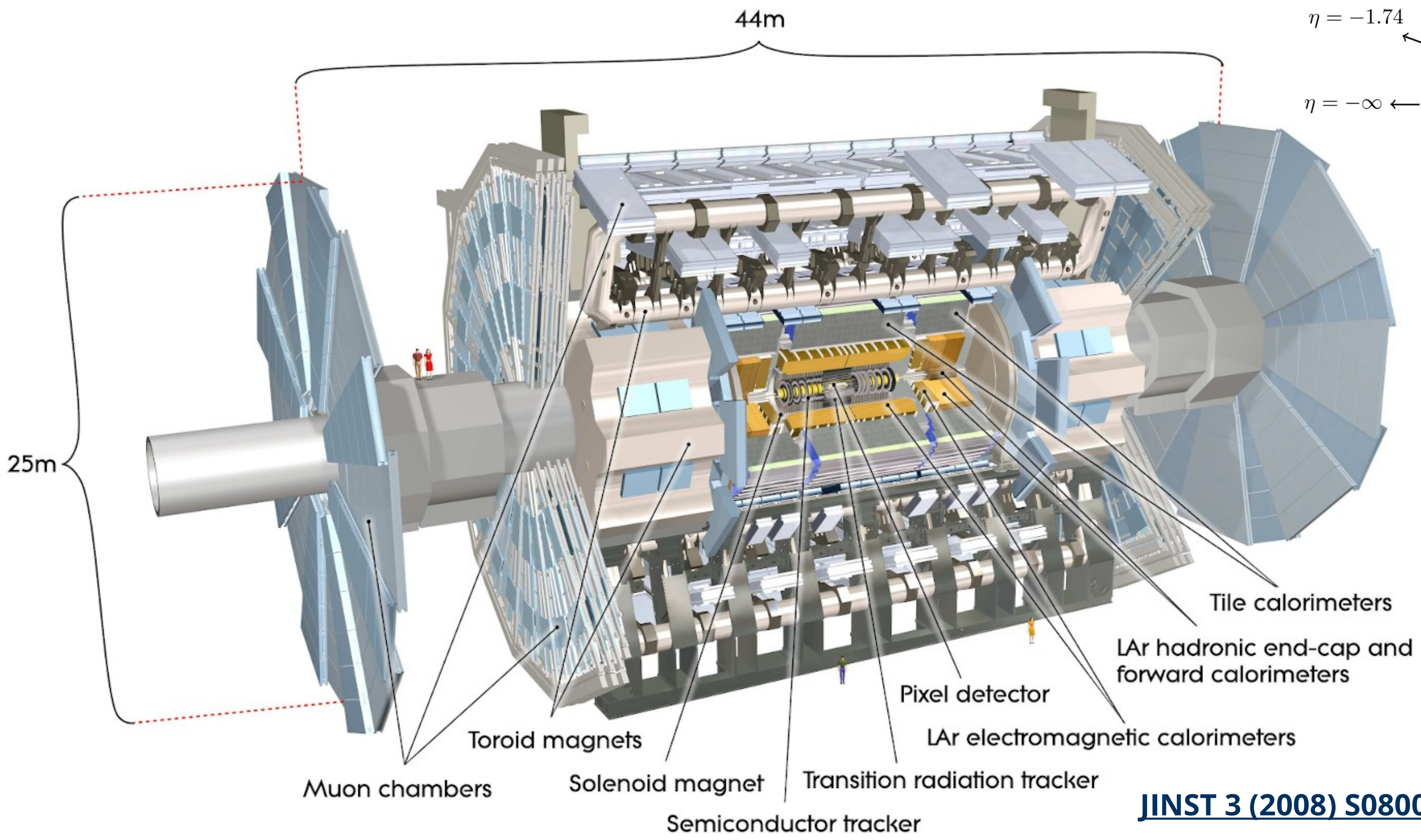
- LAr calorimeter cells set to HV of **1-2.5 kV**
- HV values monitored via **D**etector **C**ontrol **S**ystem (DCS) and stored in conditions DB
- Only ~6% of HV regions working at reduced voltage
- Corrections can be applied during energy reconstruction
  - ⇨ Only small loss of accuracy

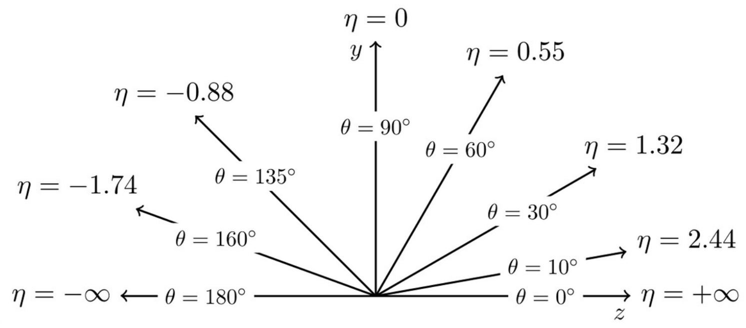




LArCaloPublicResultsDetStatus

The ATLAS detector





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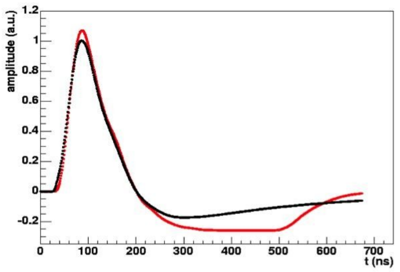
Calibration system



LArCaloPublicResultsDetStatus

$$E_{\text{cell}} = F_{\mu\text{A}\to\text{MeV}} \cdot F_{DAC\to\mu\text{A}} \cdot \frac{1}{\frac{\text{M}_{\text{phys}}}{\text{M}_{\text{cali}}}} \sum_{i=1}^{M_{\text{ramps}}} R_i \left[\sum_{j=1}^{N_{\text{samples}}} a_j \left(s_j - p \right) \right]^i$$

ADC to DAC (Ramps)

Pulse Samples

Cell energy

Sampling fraction

Calibration board

Optimal Filtering Coefficients

Pedestals

Typical calibration data set (in 3 gains):

- Pedestal (random triggers) → baseline, noise, auto-correlation
- Ramp (set of different amplitudes) → electronics gain
- Delay (set of different phases) → pulse shape, obtain OFCs

Phase-I electronics upgrades

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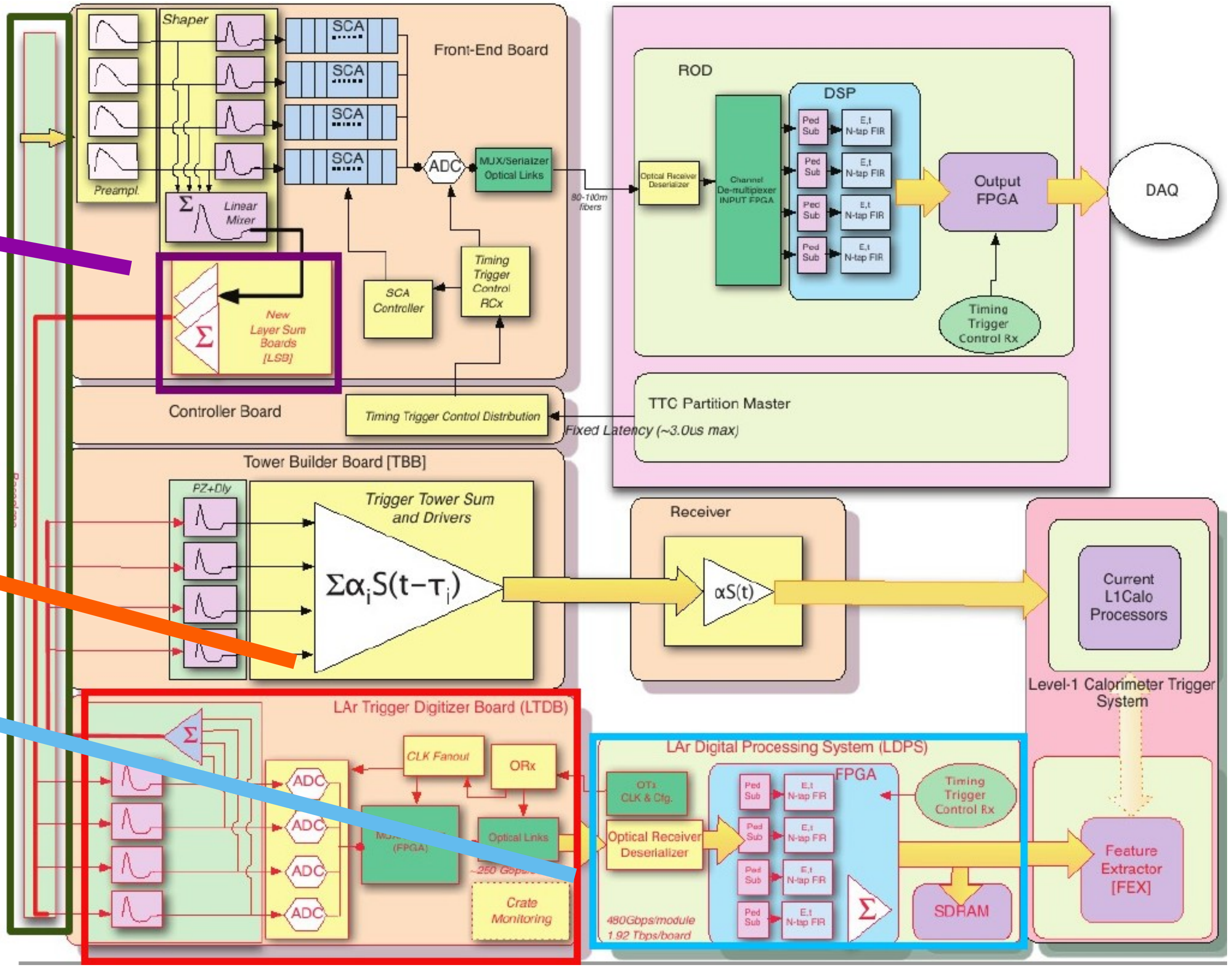
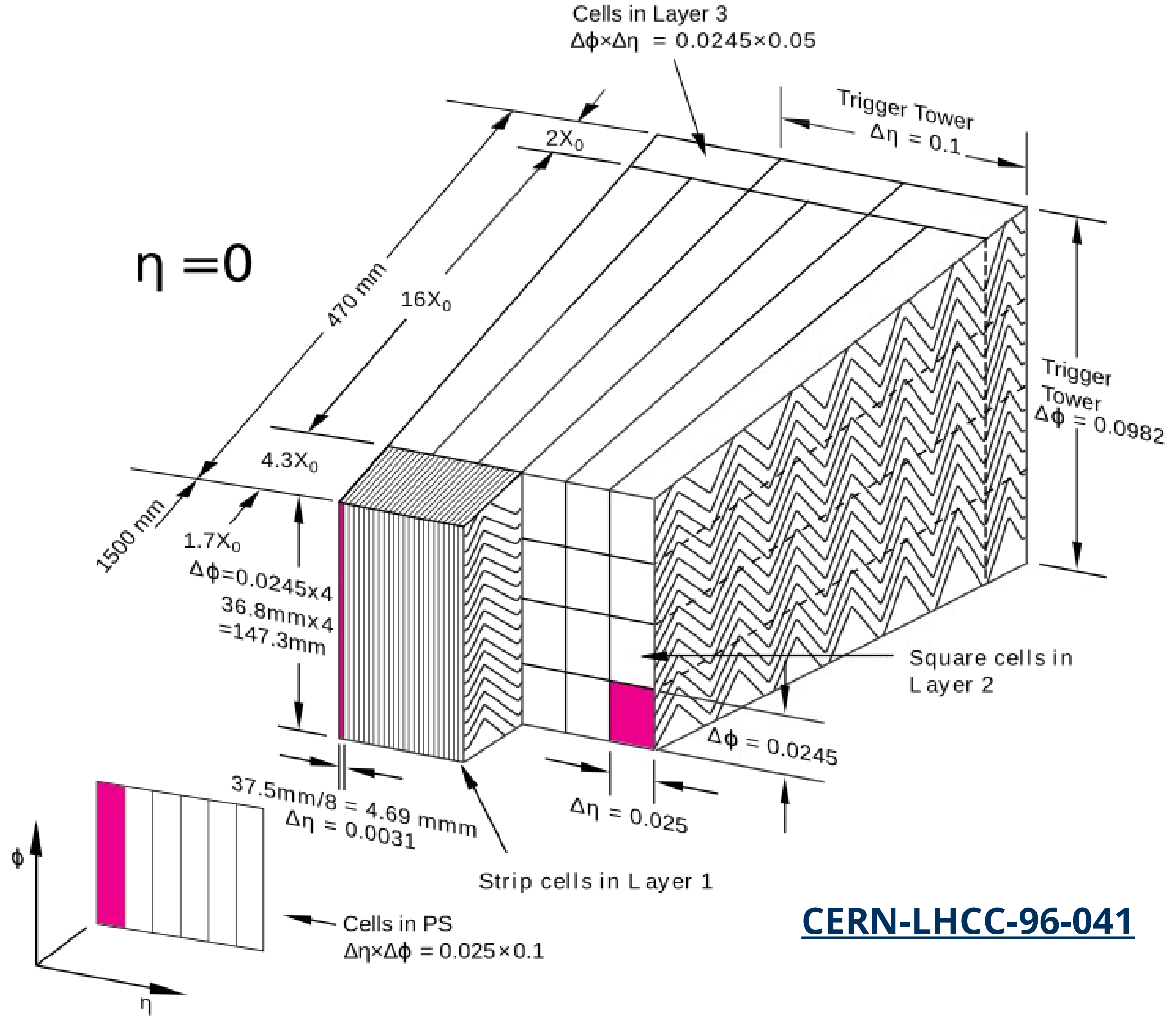
- Replace **Layer Sum Boards** to account for finer sums needed
- Replace **baseplanes** to cope with higher data flux and new boards
- New boards to **digitize SC signals**
- New system to **reconstruct energies** and transmit them to new trigger system (@40 MHz)



EM calorimeter design

- Copper/kapton electrodes
- Lead absorber
- 2 mm LAr gaps in barrel
  - ⇨ 0.9–2.8 mm in endcaps
- Accordion geometry: uniform coverage in Φ
- Readout from front and back, signals led to Front-End electonics outside cryostat
  - ⇨ Warm low-noise GaAs preamps
- Presampler used to correct for energy loss upstream of the calorimeter
- Front layer used in particle identification (photon vs. π^0)



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